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ON THE TEMPERATURE COEFFICIENTS OF MAGNETS MADE OF CHILLED CAST IRON.

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INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATIONS FROM THE RUMFORD FUND.

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Besides a number of d'Arsonval galvanometers, furnished with hardened forged steel magnets, from the shops of well known makers in America and in Europe, there are in the Physical Laboratories of Harvard University about thirty similar instruments in which the permanent fields are due to chilled and seasoned cast iron magnets. These latter have proved very satisfactory, and, after a trial of three years, we are about to add to their number.

Although chilled cast iron magnets were used years ago in some forms of telephones, straight magnets are most conveniently made of steel; indeed if they are to be employed in measuring the intensity of the earth's field, the best tool steel, ground slowly into shape under water after the hardening, is not too homogeneous for the purpose. Steel for permanent magnets, however, needs special skill in the handling, if the results are to be satisfactory, and not every successful tool maker knows how to forge and to harden, well and quickly, even a horseshoe magnet, unless it be of very simple form. Two straight, hollow bar magnets were made and ground most carefully for use in the Jefferson Physical Laboratory, by a firm which manufactures machine tools of the highest grade. These were supposed to be as nearly alike as possible, but they proved to be magnetically very different, for the permanent moment of one was twice that of the other.

Of late I have been using magnets made of soft iron castings, subsequently chilled, to furnish the artificial field in an oil damped amperemeter, and in a similar voltmeter firmly set up in the laboratory, and, since it was desirable that the indications of these instruments should be trustworthy within one part in a thousand of their larger deflections, it became necessary to test the permanency of the magnets, and to

determine their temperature coefficients. This paper gives the results of measurements made on a number of magnets of this kind.

Most of the magnets experimented upon were made of castings chilled by Mr. G. W. Thompson, the mechanician of the Jefferson Physical Laboratory, who has had a great deal of experience with the process. They were first heated to a bright red in a gas furnace under a power blast, and then plunged into a cold acid bath kept in violent agitation. The castings thus hardened were relaxed by long exposure to boiling water or steam, then magnetized to saturation, and finally seasoned, after prolonged boiling, by being alternately heated in steam and cooled in tap water. The whole seasoning process reduced the magnetic moment of each specimen by perhaps twenty per cent of the value it had just after the magnetization. If, after a magnet has been seasoned, its temperature be suddenly raised from 0° C. to 100° C. and then as suddenly lowered again, it may not wholly recover its original strength until after the lapse of an hour or two: if, however, the range be only 40° or 50° C., I have been unable to detect any lag in the attainment of the whole of the original moment after the heating.

Although there is no advantage in using cast iron for straight magnets, I had a number made for comparison with fine steel magnets of the same dimensions. The cast iron magnets looked rough in comparison with the others, but the moments of a large number of them seemed to differ less among themselves than the moments of the same number of the steel magnets. The strongest steel magnet that I tested had a moment about four per cent greater than that of the strongest cast iron magnet, but the average moment of the cast iron magnets was practically the same as (in fact two per cent greater than) the average of the seasoned steel magnets.

In determining the temperature coefficients, the straight magnet to be experimented upon was fixed firmly in a non-magnetic holder inside a non-magnetic tube so as to be in Gauss's A Position east of a mirror magnetometer. By the help of a system of pipes and cocks, tap water, steam, or a stream from a bath water heater at almost any desired temperature, between 15° C. and 100° C. could be sent through the tube containing the magnet. On the west of the magnetometer, so placed in Gauss's A Position as to bring the needle back exactly into the meridian, was a short, seasoned, compensating magnet, fixed wholly within a wooden holder and completely shielded from sudden temperature changes. If a_0 is the needle deflection which the compensating magnet would cause if the magnet to be tested were removed, M_0, the moment of the last

named magnet at the temperature t_0 at which the adjustments have been made, and M, the moment of this magnet when, its temperature having become raised to t, the needle is deflected through the angle α,

$$\frac{M_0 - M}{M_0} = \frac{\tan \alpha}{\tan \alpha_0}.$$

Since the temperature coefficients of seasoned bar magnets of a given length and of given material are in general larger the greater the cross section of the bar, it is necessary in comparing materials to take magnets of nearly the same dimensions. Besides a number of chilled cast iron magnets 18 centimeters long and about 0.95 centimeters in diameter, I had many carefully made steel magnets of the same area of cross section and of almost the same length. In the case of all these, the rate of loss of moment per degree of rise of temperature was greater at higher temperatures than at low; we may, however, for the purpose of comparison, use the mean loss, per degree, of the magnetic moment, when the magnet is heated from about 10° C. to 100° C., expressed in terms of the moment at the lower temperature. These mean losses were found to be

0.00042 in the case of the seasoned chilled iron magnets.

0.00046 in the case of the seasoned magnets made of "Crescent Steel Drill Rod."

0.00046 in the case of the seasoned magnets made of Jessop's Round Black Tool Steel.

0.00070 in the case of the seasoned magnets made of Jessop's Square Tool Steel.

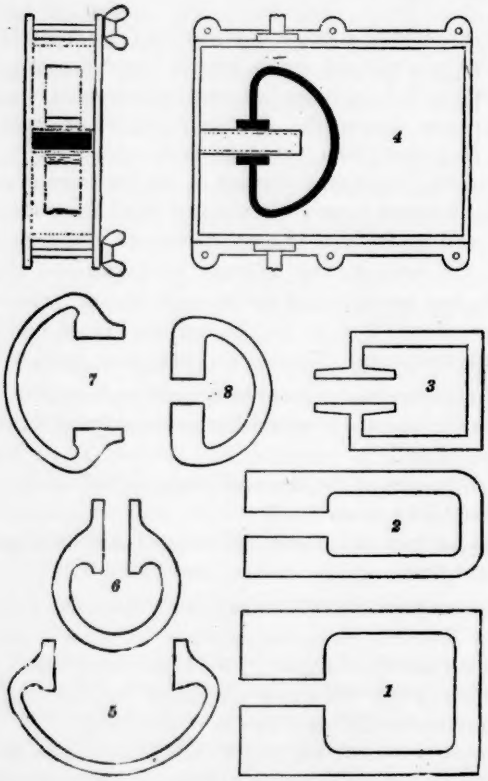
I had bar magnets made of many other materials, for instance of Jessop's and Mushet's self-hardening steels, but none of exactly the dimensions of the cast iron magnets. No kind of steel that I tested had, however, when proper allowance was made for dimensions, quite so small a temperature coefficient as the chilled iron.

The mean temperature coefficient of chilled cast iron magnets 18 centimeters long and 1.25 centimeters in diameter, as obtained from a number of specimens, was 0.00056, which is very low.

The forms of some of the magnets which we have used (either singly or with others of the same kind), in various instruments, are shown in the subjoined figure. The shapes marked 1, 2, 3, 6, are employed, with the long way of the opening between the poles vertical, in d'Arsonval galvanometers; two or three castings of the shape marked 4, and a number of thin plates of the shape marked 8, are used together in other instru-

ments of the same kind. Magnets of the shapes marked 5 and 7 produce the artificial fields in laboratory amperemeters and voltmeters.

For our present purpose we may define the temperature coefficients of one of these magnets as the rate of change of the whole magnetic induction across a given surface between the poles, when the temperature of



the magnet is raised by one degree. This can be measured with sufficient accuracy, by pulling out, from a definite position between the jaws, a coil of suitable shape made of manganine wire and connected with a ballistic galvanometer. In order to be able to make the determinations conveniently I had a brass box made of the shape indicated in the figure. The box itself was first cast in one piece, and then a slot for the coil was

cut on a milling machine, and a rectangular cavity, open to the outside air but closed to the inside of the box, was constructed by soldering two thin pieces of brass into the end and top of the slot. Into this cavity a set of forms carrying thin coils of the shapes needed, fitted exactly. The box itself, and the cover, were mounted on the face plate of a lathe and turned off smooth, so that when a piece of rubber packing was inserted between the two, and the whole was screwed together, the case thus made was water-tight. The box was mounted on a wooden frame which had sliders for the forms which carried the coils. The magnet to be tested was fastened firmly in place by a holder not shown in the figure, and the box was connected with a set of pipes so that cold water, warm water, or steam could be sent through it at pleasure.

The temperature coefficient of a bent cast iron magnet, as defined above, generally increases with the temperature, but for purposes of comparison, we may use the mean value K of this coefficient between 10° C. and 100° C.

Three magnets of the form marked 1, chilled by Mr. Thompson and weighing as much as 1250 grams each (nearly three pounds), gave for K the values 0.00036, 0.00037, and 0.00034 respectively; another magnet of the same pattern treated by a maker of hardened cast iron machinery, yielded the value 0.00082. Whatever the secret process employed in this last case, the resulting magnet was by no means so useful as those made from castings chilled in the manner described above.

Unchilled castings make very undesirable magnets, for the temperature coefficients are usually five or six times as large as in the case of chilled magnets, and it seems impossible to get their magnetic moments really permanent. Curiously enough the chilling process makes a casting less brittle than before, and causes the grain of a fracture to be finer and more uniform.

The values of K seem to indicate that the whole interior of the casting is affected by the chilling, whereas it is extremely difficult to harden a thick piece of steel uniformly. It did not appear that a magnet made up of a lot of thin plates chilled separately had a smaller temperature coefficient than a solid magnet of the same dimensions.

Castings of the shapes marked 3, 4, and 6 weighed about 260 grams, 160 grams, and 500 grams, respectively, and yielded for K the values 0.00040, 0.00040, 0.00031. The actual temperature coefficients at low temperatures are always less than these mean values, and in the case of the last mentioned form the coefficient is not greater than 0.00013 between 10° C. and 40° C. I have myself never found a value quite so small as

this for a massive steel magnet, though several observers have obtained extremely low coefficients for very slender steel wires, and even negative coefficients for comparatively weak magnets made of some alloys.

Using such chilled magnets as I have described, and employing composite galvanometer coils of manganine and copper, with permanent manganine shunts, it is not difficult to make a cheap fixed amperemeter, the indications of which shall be almost wholly independent of the room temperature. In the case of a d'Arsonval galvanometer of the usual form, slight temperature changes in the torsional rigidity of the suspension wire have to be taken into account.

Jefferson Physical Laboratory,
December, 1902.